## Title

A hybrid mobile approach for population-wide HIV testing in rural east Africa: an observational study.



## Journal

The lancet. HIV, 3(3)

## ISSN

2405-4704

## Authors

Chamie, Gabriel
Clark, Tamara D
Kabami, Jane
et al.

## Publication Date

2016-03-01

## DOI

10.1016/s2352-3018(15)00251-9

Peer reviewed

HHS Public Access

Author manuscript

*Lancet HIV*. Author manuscript; available in PMC 2017 March 01.

Published in final edited form as:

*Lancet HIV*. 2016 March ; 3(3): e111–e119. doi:10.1016/S2352-3018(15)00251-9.

# A hybrid mobile HIV testing approach for population-wide HIV testing in rural East Africa: an observational study

**Gabriel Chamie, MD**[1], **Tamara D Clark, MHS**[1], **Jane Kabami, MPH**[2], **Kevin Kadede, MA**[3], **Emmanuel Ssemmondo, MBChB**[2], **Rachel Steinfeld, MHS**[1], **Geoff Lavoy**[2], **Dalsone Kwarisiima, MBChB**[2], **Norton Sang, BSCCM**[3], **Vivek Jain, MD**[1], **Harsha Thirumurthy, PhD**[4], **Teri Liegler, PhD**[1], **Laura B Balzer, PhD**[5], **Maya L Petersen, PhD**[6], **Craig R Cohen, MD**[7,*], **Elizabeth A Bukusi, PhD**[3,*], **Moses R Kamya, M.Med**[8,*], **Diane V Havlir, MD**[1,*], and **Edwin D Charlebois, PhD**[9,*]

[1]Division of HIV, Infectious Diseases and Global Medicine, University of California San Francisco, San Francisco, California, USA [2]Makerere University - University of California Research Collaboration, Kampala, Uganda [3]Centre for Microbiology Research, Kenya Medical Research Institute, Nairobi, Kenya [4]Gillings School of Global Public Health, University of North Carolina at Chapel Hill, North Carolina, USA [5]Department of Biostatistics, Harvard T.H. Chan School of Public Health, Boston, Massachusetts, USA [6]University of California Berkeley School of Public Health, Berkeley, California, USA [7]Department of Obstetrics, Gynecology and Reproductive Sciences, University of California San Francisco, San Francisco, California, USA [8]Department of Medicine, School of Medicine, Makerere University College of Health Sciences, Kampala, Uganda [9]Department of Medicine, Center for AIDS Prevention Studies, University of California San Francisco (UCSF), San Francisco, California, USA



Corresponding author: Gabriel Chamie, MD, MPH, Assistant Professor of Medicine, UCSF Division of HIV, Infectious Diseases and Global Medicine, San Francisco General Hospital, UCSF Box 0874, San Francisco, CA 94143-0874, USA, Tel: 001-415-476-4082, ext 445, Gabriel.chamie@ucsf.edu.

*Full Professors

**Contributors**

GC, DH and EC contributed to the study design, data analysis and interpretation, literature search, figures, and writing of the manuscript. GC had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. TC, LB, DK, and MP contributed to the study design, data analysis and data interpretation, and writing of the manuscript. LB conducted the collaborative-targeted maximum likelihood estimation analyses. JK, ES, RS, NS, GL and KK contributed to the data collection and data interpretation for the manuscript. VJ, HT, TL, CC, and MK contributed to the study design, literature search, data interpretation and writing of the manuscript. EB contributed to the study design and data interpretation for the manuscript.

**Declaration of interests**

All authors report grants from National Institutes of Health (NIH) during the conduct of the study. GC, DK, VJ, HT, CC, MP, MK, DH and EC report grants from NIH outside the submitted work. VJ reports grant support from Gilead Sciences outside of the submitted work. DH reports non-financial support from Gilead Sciences, during the conduct of the study. HT reports grants from Bill & Melinda Gates Foundation and the International Initiative for Impact Evaluation outside of the submitted work. CC reports grants from Bill & Melinda Gates Foundation, grants from CIFF, personal fees from Legal consulting about malpractice case, personal fees from Symbiomix Inc., outside the submitted work. None of the authors have been paid by a pharmaceutical company or other agency to write this manuscript.

## Abstract

**Background—**Despite large investments in HIV testing, only 45% of HIV-infected persons in sub-Saharan Africa are estimated to know their status. Optimal methods for maximizing population-level testing remain unknown. We sought to demonstrate the effectiveness at achieving population-wide testing coverage of a hybrid mobile HIV testing approach.

**Methods—**From 2013–2014, we enumerated 168,772 adult (≥15 years) residents of 32 communities in Uganda (N=20), and Kenya (N=12) using a door-to-door census. "Stable" residence was defined as living in community for ≥6 months over the past year. In each community we performed 2-week multi-disease community health campaigns (CHC) that included HIV testing, counseling, and referral to care if HIV-infected; CHC non-participants were approached for home-based testing (HBT) over 1–2 months. We determined population HIV testing coverage, and predictors of testing via HBT (vs. CHC) and non-testing.

**Findings—**HIV testing was achieved in 89% of stable adult residents (131,307/146,906). HIV prevalence was 9.6% (13,043/136,033 stable and non-stable adults); median $CD4^+$ T-cell count was 514 cells/μL (IQR: 355–703). Among stable adults tested, 43% (56,106/131,307) reported no prior testing. Among HIV-infected adults, 38% (4,932/13,043) were unaware of their status. Among stable CHC attendees, 99.5% (104,635/105,170) accepted HIV testing. Of stable adults tested, 80% (104,635/131,307, range: 60–93%) tested via CHCs. In multivariable analyses of stable adults, predictors of non-testing included male gender (risk ratio [RR]: 1.52, 95% CI: 1.48–1.56), single marital status (RR: 1.70, 95% CI: 1.66–1.75), Kenyan residence (RR: 1.46, 95% CI: 1.41–1.50, vs. Ugandan), and out-of-community migration for ≥1 month in past year (RR: 1.60, 95% CI: 1.53–1.68). Testing was more common among farmers (RR: 0.73, 95% CI: 0.67–0.79) and adults with primary education (RR: 0.84, 95% CI: 0.80–0.89).

**Interpretation—**High HIV testing coverage was achieved in rural Ugandan and Kenyan communities using a hybrid, mobile approach of multi-disease CHCs followed by HBT. This approach allowed for flexibility at the community and individual level in reaching testing coverage goals. Men and mobile populations remain challenges for universal testing.


## Introduction

Despite large investments in HIV testing, only 45% of people living with HIV in sub-Saharan Africa are estimated to know their status.(1, 2) To take full advantage of recent advances in treatment as prevention,(3) there is a compelling need to increase HIV testing at the population level. On this basis, UNAIDS has established an ambitious global target of 90% HIV testing coverage by 2020.(1) However, how best to maximize population-wide testing coverage is unknown. Barriers to HIV testing are multiple, and include lack of awareness of HIV risk, minimally symptomatic early HIV disease, stigma, and challenges with access, costs and waiting times associated with health facility-based testing.(4–6) Moving HIV testing out of health facilities and into communities can overcome some of these barriers.(7)

Out-of-facility HIV testing approaches include home-based,(8–10) work-based,(11) index testing,(12) self-testing,(13) and community health campaigns.(14, 15) Each of these approaches has advantages, however no single approach is likely to work across diverse

settings in sub-Saharan Africa. Of these, home-based testing and mobile health campaigns have achieved the highest levels of population coverage.(7) Large-scale mobile health campaigns achieve high levels of coverage rapidly.(14–16) By incorporating multi-disease services, campaigns may normalize HIV testing as routine care, create a mechanism for coping with stigma, improve access, and reduce transport costs and waiting times.

Home-based testing (HBT) also improves access, and has proved effective in various settings.(8, 17) Unlike campaigns, HBT allows for couple counseling and reaches those who do not seek venue-based testing.(18, 19) Technologic improvements in data management, geographic information systems, and digital biometric identification now offer increasingly simple methods to enumerate large populations. This allows for a clearer understanding of who is not reached by campaigns,(16) and thus selective use of HBT. Based on the relative advantages of each mobile approach, we hypothesized that a combination of large-scale health campaigns followed by HBT of campaign non-participants could rapidly achieve 90% population testing coverage.

We sought to demonstrate the effectiveness at achieving population-wide testing coverage of a hybrid mobile HIV testing approach of multi-disease community health campaigns (CHC) followed by HBT of campaign non-participants during rapid testing scale-up in an HIV “test and treat” trial in Uganda and Kenya. We also sought to identify baseline predictors of HBT (vs. CHC-testing) among adults who tested, and of non-testing for HIV, in order to characterize populations that did not engage in campaigns and that are “hard to reach” for testing, respectively.

## Methods

### Study Design

The hybrid mobile HIV testing approach is the primary testing strategy in the Sustainable East Africa Research in Community Health (SEARCH) HIV test and treat cluster-randomized controlled Trial (NCT:01864603: https://clinicaltrials.gov/ct2/show/NCT01864603). The SEARCH Trial consists of 32 communities (Figure 1) selected from 54 candidate communities that met initial eligibility criteria of a rural community (defined as one or more national geopolitical units, just above the village level: i.e. a “parish” in Uganda, and a “sub-location” in Kenya), with population 10,000, within the catchment area of a President’s Emergency Plan For AIDS Relief (PEPFAR)-supported HIV clinic in southwestern Uganda, eastern Uganda or western Kenya. We performed ethnographic mapping, reviewed national census and epidemiologic data for each candidate community, and then selected 16 matched pairs based on region, population density, occupational mix, access to transport routes, and number of trading centers.(20) All 32 communities underwent census enumeration followed by the hybrid mobile HIV testing approach.

### Procedures

Study staff performed baseline resident enumeration and trial enrollment in all communities using a 2–4 week per community, door-to-door census. Census staff, working with village leaders, visited all residential structures within each community. The census interview

consisted of: 1) enumeration of all persons who lived on the property for ≥1 month in the year preceding the census visit; 2) digital biometric fingerprint measurement (U.are.u 4500 reader, Digital Persona, Crossmatch, Florida, USA) of all available household members; 3) measurement of geographic positioning system coordinates of the home; and 4) an interview to obtain demographic, household socioeconomic, and migration data. “Stable” residence was defined as living in the community for ≥6 months over the past year.

Before initiating mobile HIV testing, study staff met with local leaders to solicit advice on CHCs and HBT implementation. Local leaders then reached out to their communities to provide information about the multi-disease CHC. Study staff co-implemented mobilization activities with local leaders one month before the CHC. Information was disseminated using posters and pamphlets, announcements during religious services and community events, question and answer sessions at gathering places (e.g. bars and markets), and during the census. Small non-monetary prizes were awarded to randomly selected CHC participants as a way of promoting attendance (prizes totaled ≤US$ 2,000/community).

Two-week mobile, multi-disease CHCs were conducted in partnership with the Uganda and Kenya Ministries of Health (MoH), at well-known, convenient community locations. Services included rapid, finger prick-blood based HIV antibody testing and counseling (HTC) for all persons ≥18 months of age (regardless of self-reported HIV status) using MoH test kits and testing algorithms, followed by point-of-care $CD4^+$ T cell count measurement (PIMA, Inverness), provision of a 30-day supply of trimethoprim-sulfamethoxazole, and referral to HIV care if HIV-infected. Non-HIV services varied by community, and included services such as hypertension and diabetes screening, malaria rapid diagnostic testing for participants with fever, male condom distribution, referral for medical male circumcision, family planning and cervical cancer screening, and Vitamin A and albendazole treatment for young children. Residence status was defined by baseline census enumeration. Fingerprint biometrics were used to verify resident status and record CHC attendance on-site at the CHC entrance prior to HIV testing, using USB-enabled fingerprint scanners (U.are.u 4500 reader, Digital Persona) connected to tablet computers that each contained the census database; if fingerprint matching failed, name-based matching to the census database was used, with verification of name-matched participants’ household members as an added cross-check in the event of multiple similar names in the same community. Self-reported residence at time of CHC participation was also accepted to define resident status, provided self-reported residents could be linked to census-enumerated households. Daily reports on the number of residents seen each CHC day were reviewed to monitor testing coverage in real-time and identify demographic groups for additional mobilization efforts.

Using census enumeration and CHC attendance data, we identified residents who did not engage in HIV testing at CHCs. These residents were approached for testing at their homes, or a place of their choosing, over 1–2 months, in order to reach minimum testing coverage of 80% among stable men and women residents (age 15–50). HTC and referral services offered during HBT were identical to the CHC; however, non-HIV services were not provided. Resident identity was verified using fingerprint biometrics in the same fashion as CHC identification. If a CHC non-participant was not home during initial HBT visit, staff attempted to contact them by phone and/or return up to three times.

All HIV-infected persons identified at CHCs or HBT received one-on-one post-test counseling that included information on living with HIV, preventing transmission, the benefits of linking to care and treatment, and the logistics of attending the local ART-providing clinic. Face-to-face introductions to local clinic staff occurred at CHCs. Specific appointment dates within two months of testing were provided to each HIV-infected person. HIV-infected persons with CD4 counts <200 cells/μL or pregnant at time of testing were given priority appointments, within one week. Staff provided transport vouchers to all HIV-infected persons, for reimbursement upon linking to care.

## Statistical Analyses

Predictors of no prior HIV testing and testing at home rather than CHC among stable adults who tested, and non-testing for HIV among all stable adults, were estimated using collaborative targeted maximum likelihood estimation (C-TMLE).(21) Specifically, we estimated the marginal relative risk associated with each predictor, after controlling for the other predictor variables. C-TMLE was implemented instead of standard logistic regression to avoid the modeling assumptions inherent in parametric regression, and to help alleviate problems due to collinearity of multiple predictor variables. All analyses were adjusted for clustering by household. A household wealth index across all communities was calculated using principal components analysis based on ownership of livestock (cows, goats and poultry) and household items (clock, radio, television, phone, refrigerator, bicycle, motorcycle and electricity).(22)

## Geospatial Analysis

One community per region was selected for geospatial mapping in order to visually demonstrate changes in HIV testing coverage among stable adults at three time periods: 1) prior to the hybrid approach (i.e. self-reported prior testing in the preceding year); 2) after CHC implementation; and 3) after implementing the hybrid approach. Maps were created using ArcGIS (Esri, Redlands, CA), by determining the density of persons meeting an outcome criterion per $km^2$, and then standardizing color intensity scales of the outcome densities to allow for cross-community comparison.

The Makerere University School of Medicine Research and Ethics Committee and the Ugandan National Council on Science and Technology (Uganda), and the Kenya Medical Research Institute Ethical Review Committee (Kenya), and the University of California San Francisco Committee on Human Research approved the consent procedures and the study. All participants provided informed consent in their preferred language.

## Role of the funding source

The sponsors of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

## Results

Between April 2013-June 2014, the SEARCH Trial enumerated 335,005 people, including 168,772 adults (≥15 years), during study censuses: 103,580 persons in southwestern Uganda, 110,113 in eastern Uganda, and 121,312 in Kenya (Figure 1). National census projections estimated a population of 345,181 persons in the 32 communities.(23, 24) Average duration of study census enumeration was 19 (range: 8–31) days/community. Stable residents represented 87% (146,906 persons) of enumerated adults. Baseline characteristics of enumerated adults are shown in Table 1.

Over one year, 89% (131,307/146,906) of stable adult residents tested for HIV using a hybrid strategy of CHC followed by HBT of CHC non-participants. HIV testing coverage of stable adult residents by testing modality and demographic sub-group are shown in Table 2. Testing coverage at CHCs ranged from 52–82% across the 32 communities. Testing coverage using the hybrid approach was 22% (4,726/21,866) among non-stable adult residents, and 81% (136,033/168,772) among all adult residents (stable and non-stable). HIV prevalence was 9.6% (13,043/136,033 adults; 95% CI: 9.4–9.8%), with a median $CD4^+$ count of 514 (IQR: 355–703) cells/μL among HIV-infected adults. Adult HIV prevalence was 6.5% (2,861/43,942; 95% CI: 6.3–6.7%) in southwestern Uganda, 3.4% (1,539/45,175; 95% CI: 3.2–3.6%) in eastern Uganda, and 18.4% (8,643/46,916; 95% CI: 18.1–18.8%) in western Kenya.

CHC-based testing was the most common mode of HIV testing. Among stable adult residents who tested for HIV, 104,635/131,307 (80%, range 60–93% across communities) tested at CHCs. Among adult CHC attendees, 99.5% (104,635/105,170) accepted HIV testing. The average number of CHC days/community was 12.5 (range 12–17). Average daily CHC participation by both adults and children was 590 residents/day (724 residents/day in eastern Uganda, 597/day in southwestern Uganda, and 484/day in Kenya) and an overall mean of 290 adult residents/day. The median duration of time spent participating in CHC activities was 43 (IQR: 31–61) minutes/person. CHC-based testing identified 76% (9,967/13,043) of all HIV-infected adults diagnosed with the hybrid approach. Characteristics of HIV-infected stable adults diagnosed at CHC are shown in Table 2.

Among stable adult residents who tested for HIV, 26,672/131,307 (20%) tested via HBT, with a range of 7–40% across communities. Among adults encountered during HBT, 79% (26,672/33,697) accepted HIV testing. The average number of home visits was 1.6/person. HBT identified 24% (3,076/13,043) of all HIV-infected adults (stable and non-stable) diagnosed with the hybrid approach. Characteristics of HIV-infected stable adults diagnosed at HBT are shown in Table 2. An average of 26 (range: 11–62) days/community was spent conducting HBT.

Of stable adults tested, 43% (56,106/131,307) reported no prior HIV testing vs. 51% (2,423/4,726) of non-stable adults. Among HIV-infected adults, 38% (4,932/13,043) reported being unaware of their status prior to testing (21% [2,754/13,043] reported their last HIV test was negative or unknown, and 17% [2,178/13,043] reported no prior testing). Of

HIV-uninfected stable adults reporting prior testing, 41% (26,269/64,336) reported testing >1 year ago. Predictors of no prior testing among stable adults who tested for HIV are shown in Table 3. In multivariable analyses, risk factors with the largest risk ratios included male gender (relative risk [RR]: 1.28, 95% CI: 1.26–1.29), single marital status (RR: 1.33, 95% CI: 1.31–1.34 vs. non-single), and student occupation (RR: 1.21, 95% CI: 1.18–1.25 vs. jobless).

Predictors of HBT (i.e. CHC non-participation) among stable adults who tested are shown in Table 3. In multivariable analyses, risk factors with the largest risk ratios included Kenya residence (RR: 1.82, 95% CI: 1.77–1.87 vs. Uganda), male gender (RR: 1.48, 95% CI: 1.45–1.51), single marital status (RR: 1.39, 95% CI: 1.36–1.42), and migration out of the community for ≥1 month (RR: 1.36, 95% CI: 1.31–1.40, vs. no migration). HIV-infected status was also an independent predictor of increased probability of HBT (RR: 1.12, 95% CI: 1.08–1.16, vs. HIV-uninfected).

Predictors of non-testing for HIV among stable adults are shown in Table 3. Risk factors with the largest risk ratios included male gender (RR: 1.52, 95% CI: 1.48–1.56), single marital status (RR: 1.70, 95% CI: 1.66–1.75), 30–39 year old age group (RR: 1.58, 95% CI: 1.52–1.65, vs. 15–19 years), Kenya residence (RR: 1.46, 95% CI: 1.41–1.50), and migration out of the community for ≥1 month (RR: 1.60, 95% CI: 1.53–1.68, vs. no migration).

HIV testing coverage before, during, and after implementing the hybrid approach is shown in three selected communities (one/region) with variable CHC-based testing coverage (Nyatoto having the lowest CHC testing coverage of all 32 communities) in Figure 2.

## Discussion

We achieved 89% HIV testing coverage of enumerated stable adult residents across 32 communities in Uganda and Kenya using a novel, hybrid mobile HIV testing approach of multi-disease CHCs, followed by HBT of CHC non-participants. This hybrid approach allowed for flexibility in testing modality use across multiple communities with heterogeneous HIV prevalence and prior testing rates. The findings are important in light of recent UNAIDS targets for HIV treatment scale-up, including an ambitious target that 90% of HIV-infected persons will know their status by 2020.(1) We show that rapidly achieving UNAIDS testing coverage goals across a variety of rural settings is feasible using this hybrid approach.

Our hybrid mobile testing approach demonstrates flexibility and efficiency in reaching HIV testing targets by allowing the balance between campaigns and HBT to vary in response to each community's level of testing coverage at campaigns. Campaign-based testing coverage ranged from 52–82% of stable adult residents, and the hybrid strategy allowed us to adapt the amount of HBT accordingly. The hybrid approach also allows for community input on location of mobile testing sites, and for individuals to self-select the modality best suited to them. Even in western Kenya, an area with high adult HIV prevalence, the testing goal was achieved with increased HBT following CHCs. With data from rapidly conducted censuses, sub-groups that test at low rates can be targeted for more intensive mobilization and testing

efforts, including the selective use of incentives for testing. This built-in efficiency may reduce implementation costs.

This approach has several novel features. To our knowledge, it is the first to combine out-of-facility testing interventions strategically to maximize testing coverage. Unlike prior estimates of population testing coverage, our enumeration of a large, diverse target population with fingerprint biometric measures prior to mobile testing, allowed for rigorous measurement of population coverage and identification of persons who fail to test.(9, 14, 25) Lastly, the use of CHCs as the initial modality for rapid testing scale-up is a novel feature of our approach.

Integrating multi-disease services at CHCs demonstrates how HIV testing interventions can complement and enhance other public health priorities. While achieving HIV testing targets, CHCs can be leveraged to screen for communicable and non-communicable diseases, promote children's health, and provide referral to treatment and preventive services. The presence of non-HIV health services may normalize HIV testing and provide a mechanism to cope with stigma for people seeking HIV testing. Multi-disease services may also serve as an incentive for repeat testing among persons who have tested HIV negative in the past (indeed, 21% of HIV-infected adults we identified reported a prior negative test), and for counseling on linkage to care among HIV-infected persons aware of their status but not in care.

Despite high HIV testing coverage, men, single adults, and mobile persons remain challenging sub-populations for achieving universal testing. Evidence of a gender disparity in testing was observed in both increased need for HBT, and increased risk of non-testing, among men. Across sub-Saharan Africa, men test for HIV at substantially lower rates than women.(2) Consequently, HIV-infected men are diagnosed later in disease, and are less likely to link to care and start ART than women.(26–28) Low testing uptake among men therefore poses an enormous barrier to HIV prevention strategies. This gender disparity may explain, in part, the persistently high HIV incidence rates among 15–20 year old women in sub-Saharan Africa, who often have older sexual partners and acquire HIV through heterosexual transmission.(29) Despite the increased risk of non-testing among men, our approach achieved high testing coverage among men through increased HBT, with subsequent reduction in the gender disparity seen in CHC participation.

Mobile populations are likely to be a major challenge to achieving population HIV testing coverage. Coverage for our stable population was 89% vs. 22% among non-stable adults. Although men represented over half (56%) of stable adults who spent >1 month away from the community in the year prior to the census, after adjusting for gender, mobility remained a predictor of not testing for HIV. Our hybrid strategy took place over a rapid time frame, and low coverage among migrants may simply result from this sub-population being away from the community when testing was offered. Whether mobile persons are testing elsewhere is not clear. However, non-stable adults who tested in our study did report lower rates of prior testing than stable adults, and others have observed an association between migration and increased HIV risk.(30, 31) Therefore, ensuring access to testing among mobile persons remains a challenge to HIV "test and treat" approaches.

The study has several limitations. Estimates of prior HIV testing rely on self-report, and are subject to reporting bias. In enumerating our study population, we may have missed residents resulting in over-estimation of testing coverage, or misclassified some non-residents as residents. However, we conducted robust enumeration efforts and our population measurements were similar to national population projections. A potential limitation to the generalizability of our approach is that targeting HBT to CHC non-participants requires community enumeration. However, in 2014 we performed a community-led CHC that utilized existing village infrastructure (i.e. local leaders and clinical staff) to implement population enumeration before the CHC, demonstrating that low-cost, community-run enumeration is feasible.(32) Despite these limitations, our findings demonstrate an effective, flexible approach to achieving high testing coverage and characterizing who remains untested, in large, well-enumerated rural populations spanning two countries.

The hybrid, mobile HIV testing approach was effective in rapidly achieving high levels of population HIV testing coverage that are essential for the success of recent advances in HIV treatment and prevention. The hybrid approach allowed for flexibility in choice of testing modality and in how coverage goals were met, multi-disease service delivery, and rigorous identification of hard-to-reach populations for universal HIV testing scale-up. Future research on cost-effectiveness, and on how best to engage hard-to-reach populations, including men and migrants, will be necessary to maximize the policy implications of this mobile HIV testing strategy.

## Acknowledgments

**Funding:** NIH/PEPFAR

We thank the residents of the 32 SEARCH Trial communities for their generous participation in our study. We also thank the Uganda and Kenya Ministries of Health, the Director of the Kenya Medical Research Institute (KEMRI) and the Director of KEMRI's Centre for Microbiology. We gratefully acknowledge the contributions of Alexia Exarchos, Mona Farhad, and Albert Plenty from the SEARCH data team. Dr. András Ládai, MSc, PhD, assisted in the geospatial analysis and created the maps for Figure 2 as a paid consultant. This work was supported by grants from the National Institute of Allergy and Infectious Diseases (UM1AI069502 and U01AI099959; D.V.H.) at the National Institutes of Health and by the President’s Emergency Plan For AIDS Relief, the Office of the Global AIDS Coordinator, and the Office of AIDS Research.

## References

1. An ambitious treatment target to help end the AIDS epidemic. UNAIDS; 2014. 90-90-90
2. Staveteig, S.; Wang, S.; Head, S.; Bradley, S.; Nybro, E. DHS Comparative Reports No. 30. Calverton, Maryland, USA: ICF International; 2013. Demographic Patterns of HIV Testing Uptake in Sub-Saharan Africa.
3. Cohen MS, Chen YQ, McCauley M, Gamble T, Hosseinipour MC, Kumarasamy N, et al. Prevention of HIV-1 infection with early antiretroviral therapy. The New England journal of medicine. 2011 Aug 11; 365(6):493–505. Multicenter Study Randomized Controlled Trial Research Support, N.I.H., Extramural Research Support, Non-U.S. Gov't. [PubMed: 21767103]
4. Morin SF, Khumalo-Sakutukwa G, Charlebois ED, Routh J, Fritz K, Lane T, et al. Removing barriers to knowing HIV status: same-day mobile HIV testing in Zimbabwe. Journal of acquired immune deficiency syndromes. 2006 Feb 1; 41(2):218–24. Research Support, N.I.H., Extramural Research Support, Non-U.S. Gov't. [PubMed: 16394855]
5. Ostermann J, Reddy EA, Shorter MM, Muiruri C, Mtalo A, Itemba DK, et al. Who tests, who doesn't, and why? Uptake of mobile HIV counseling and testing in the Kilimanjaro Region of

Tanzania. PLoS ONE. 2011; 6(1):e16488. Research Support, N.I.H., Extramural Research Support, Non-U.S. Gov't. [PubMed: 21304973]

6. Musheke M, Ntalasha H, Gari S, McKenzie O, Bond V, Martin-Hilber A, et al. A systematic review of qualitative findings on factors enabling and deterring uptake of HIV testing in Sub-Saharan Africa. BMC public health. 2013; 13:220. Research Support, Non-U.S. Gov't Review. [PubMed: 23497196]
7. Suthar AB, Ford N, Bachanas PJ, Wong VJ, Rajan JS, Saltzman AK, et al. Towards universal voluntary HIV testing and counselling: a systematic review and meta-analysis of community-based approaches. PLoS medicine. 2013 Aug.10(8):e1001496. [PubMed: 23966838]
8. Sabapathy K, Van den Bergh R, Fidler S, Hayes R, Ford N. Uptake of home-based voluntary HIV testing in sub-Saharan Africa: a systematic review and meta-analysis. PLoS medicine. 2012; 9(12):e1001351. [PubMed: 23226107]
9. van Rooyen H, Barnabas RV, Baeten JM, Phakathi Z, Joseph P, Krows M, et al. High HIV testing uptake and linkage to care in a novel program of home-based HIV counseling and testing with facilitated referral in KwaZulu-Natal, South Africa. Journal of acquired immune deficiency syndromes. 2013 Sep 1; 64(1):e1–8. Research Support, N.I.H., Extramural Research Support, Non-U.S. Gov't. [PubMed: 23714740]
10. Tumwesigye E, Wana G, Kasasa S, Muganzi E, Nuwaha F. High uptake of home-based, district-wide, HIV counseling and testing in Uganda. AIDS Patient Care STDS. 2010 Nov; 24(11):735–41. Research Support, U.S. Gov't, P.H.S. [PubMed: 21067357]
11. Corbett EL, Dauya E, Matambo R, Cheung YB, Makamure B, Bassett MT, et al. Uptake of workplace HIV counselling and testing: a cluster-randomised trial in Zimbabwe. PLoS medicine. 2006 Jul.3(7):e238. Comparative Study Multicenter Study Randomized Controlled Trial Research Support, Non-U.S. Gov't. [PubMed: 16796402]
12. Were WA, Mermin JH, Wamai N, Awor AC, Bechange S, Moss S, et al. Undiagnosed HIV infection and couple HIV discordance among household members of HIV-infected people receiving antiretroviral therapy in Uganda. Journal of acquired immune deficiency syndromes. 2006 Sep; 43(1):91–5. Research Support, N.I.H., Intramural. [PubMed: 16885775]
13. MacPherson P, Lalloo DG, Webb EL, Maheswaran H, Choko AT, Makombe SD, et al. Effect of optional home initiation of HIV care following HIV self-testing on antiretroviral therapy initiation among adults in Malawi: a randomized clinical trial. Jama. 2014 Jul 23–30.(312)(4):372–9. Multicenter Study Randomized Controlled Trial Research Support, Non-U.S. Gov't. [PubMed: 25038356]
14. Lugada E, Millar D, Haskew J, Grabowsky M, Garg N, Vestergaard M, et al. Rapid Implementation of an Integrated Large-Scale HIV Counseling and Testing, Malaria, and Diarrhea Prevention Campaign in Rural Kenya. PLoS ONE. 2010 Aug.5(8):e12435. [PubMed: 20865049]
15. Chamie G, Kwarisiima D, Clark TD, Kabami J, Jain V, Geng E, et al. Leveraging Rapid Community-Based HIV Testing Campaigns for Non-Communicable Diseases in Rural Uganda. PLoS ONE. 2012; 7(8):e43400. [PubMed: 22916256]
16. Chamie G, Kwarisiima D, Clark TD, Kabami J, Jain V, Geng E, et al. Uptake of Community-Based HIV Testing during a Multi-Disease Health Campaign in Rural Uganda. PLoS ONE. 2014; 9(1):e84317. [PubMed: 24392124]
17. Wachira J, Ndege S, Koech J, Vreeman RC, Ayuo P, Braitstein P. HIV testing uptake and prevalence among adolescents and adults in a large home-based HIV testing program in Western Kenya. Journal of acquired immune deficiency syndromes. 2014 Feb 1; 65(2):e58–66. Research Support, Non-U.S. Gov't. [PubMed: 23846563]
18. Fylkesnes K, Sandoy IF, Jurgensen M, Chipimo PJ, Mwangala S, Michelo C. Strong effects of home-based voluntary HIV counselling and testing on acceptance and equity: a cluster randomised trial in Zambia. Social science & medicine. 2013 Jun.86:9–16. Randomized Controlled Trial Research Support, Non-U.S. Gov't. [PubMed: 23608089]
19. Labhardt ND, Motlomelo M, Cerutti B, Pfeiffer K, Kamele M, Hobbins MA, et al. Home-based versus mobile clinic HIV testing and counseling in rural Lesotho: a cluster-randomized trial. PLoS medicine. 2014 Dec.11(12):e1001768. Research Support, Non-U.S. Gov't. [PubMed: 25513807]

20. Balzer LB, Petersen ML, van der Laan MJ. Adaptive pair-matching in randomized trials with unbiased and efficient effect estimation. Statistics in Medicine. 2015 Mar 15; 34(6):999–1011. Research Support, N.I.H., Extramural. [PubMed: 25421503]
21. Gruber, S.; van der Laan, MJ. C-TMLE of an Additive Point Treatment Effect. In: van der Laan, MJ.; Rose, S., editors. Targeted Learning: Causal Inference for Observational and Experimental Data. New York: Springer-Verlag; 2011. p. 301-21.
22. Filmer D, Pritchett LH. Estimating wealth effects without expenditure data--or tears: an application to educational enrollments in states of India. Demography. 2001 Feb; 38(1):115–32. Research Support, Non-U.S. Gov't Validation Studies. [PubMed: 11227840]
23. Uganda Bureau of Statistics: Population Projections 2008–2012. Dec. 2008
24. The 2009 Kenya Population and Housing Census. Kenya National Bureau of Statistics; 2010.
25. Sweat M, Morin S, Celentano D, Mulawa M, Singh B, Mbwambo J, et al. Community-based intervention to increase HIV testing and case detection in people aged 16–32 years in Tanzania, Zimbabwe, and Thailand (NIMH Project Accept, HPTN 043): a randomised study. The Lancet infectious diseases. 2011 Jul; 11(7):525–32. Randomized Controlled Trial Research Support, N.I.H., Extramural. [PubMed: 21546309]
26. Govindasamy D, Ford N, Kranzer K. Risk factors, barriers and facilitators for linkage to antiretroviral therapy care: a systematic review. AIDS (London, England). 2012 Oct 23; 26(16): 2059–67. Review.
27. Braitstein P, Boulle A, Nash D, Brinkhof MW, Dabis F, Laurent C, et al. Gender and the use of antiretroviral treatment in resource-constrained settings: findings from a multicenter collaboration. J Womens Health (Larchmt). 2008 Jan-Feb;17(1):47–55. Multicenter Study Research Support, N.I.H., Extramural Research Support, Non-U.S. Gov't. [PubMed: 18240981]
28. Muula AS, Ngulube TJ, Siziya S, Makupe CM, Umar E, Prozesky HW, et al. Gender distribution of adult patients on highly active antiretroviral therapy (HAART) in Southern Africa: a systematic review. BMC public health. 2007; 7:63. Research Support, Non-U.S. Gov't Review. [PubMed: 17459154]
29. Dellar RC, Dlamini S, Karim QA. Adolescent girls and young women: key populations for HIV epidemic control. J Int AIDS Soc. 2015; 18(2 Suppl 1):19408. Research Support, N.I.H., Extramural. [PubMed: 25724504]
30. Camlin CS, Hosegood V, Newell ML, McGrath N, Barnighausen T, Snow RC. Gender, migration and HIV in rural KwaZulu-Natal, South Africa. PLoS ONE. 2010; 5(7):e11539. Research Support, N.I.H., Extramural Research Support, Non-U.S. Gov't. [PubMed: 20634965]
31. Kwena ZA, Camlin CS, Shisanya CA, Mwanzo I, Bukusi EA. Short-term mobility and the risk of HIV infection among married couples in the fishing communities along Lake Victoria, Kenya. PLoS ONE. 2013; 8(1):e54523. [PubMed: 23336005]
32. Kabami, J.; Kwarisiima, D.; Chamie, G.; Biira, E.; Ssebutinde, P.; Petersen, ML., et al. A Community-Led Health Campaign in a Low-resource Rural Setting in Western Uganda. International AIDS Conference; July 21, 2015; Vancouver, Canada. 2015. Abstract TUPED793

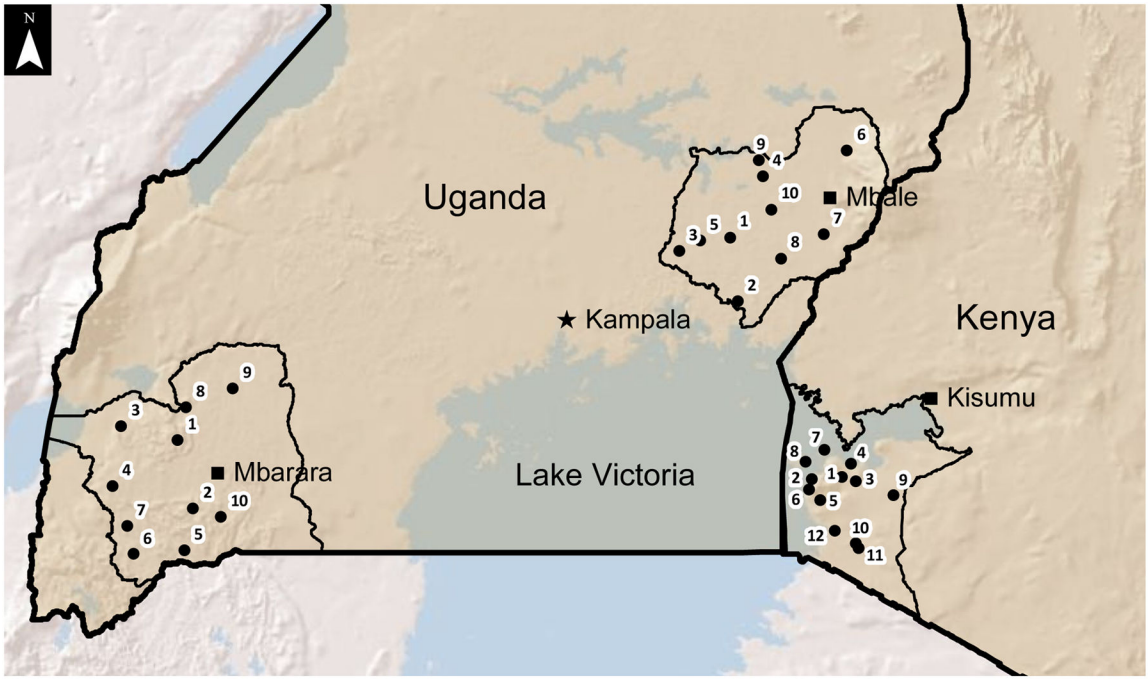


**Figure 1.**

East African Map of 32 SEARCH communities in 3 regions: Southwestern Uganda (study community names: 1. Nsiika; 2. Bugamba; 3. Rugazi; 4. Mitooma; 5. Kitwe; 6. Rubaare; 7. Rwashamaire; 8. Ruhoko; 9. Kazo; 10. Nyamuyanja), Eastern Uganda (1. Nsiinze; 2. Nankoma; 3. Kiyunga; 4. Kamuge; 5. Bugono; 6. Muyembe; 7. Merikit; 8. Kiyeyi; 9. Kameke; 10. Kadama) and Western Kenya (1. Nyatoto; 2. Nyamrisra; 3. Ogongo; 4. Kitare; 5. Magunga; 6. Kisegi; 7. Tom Mboya; 8. Sena; 9. Ongo; 10. Othoro; 11. Sibuoche; 12. Bware).

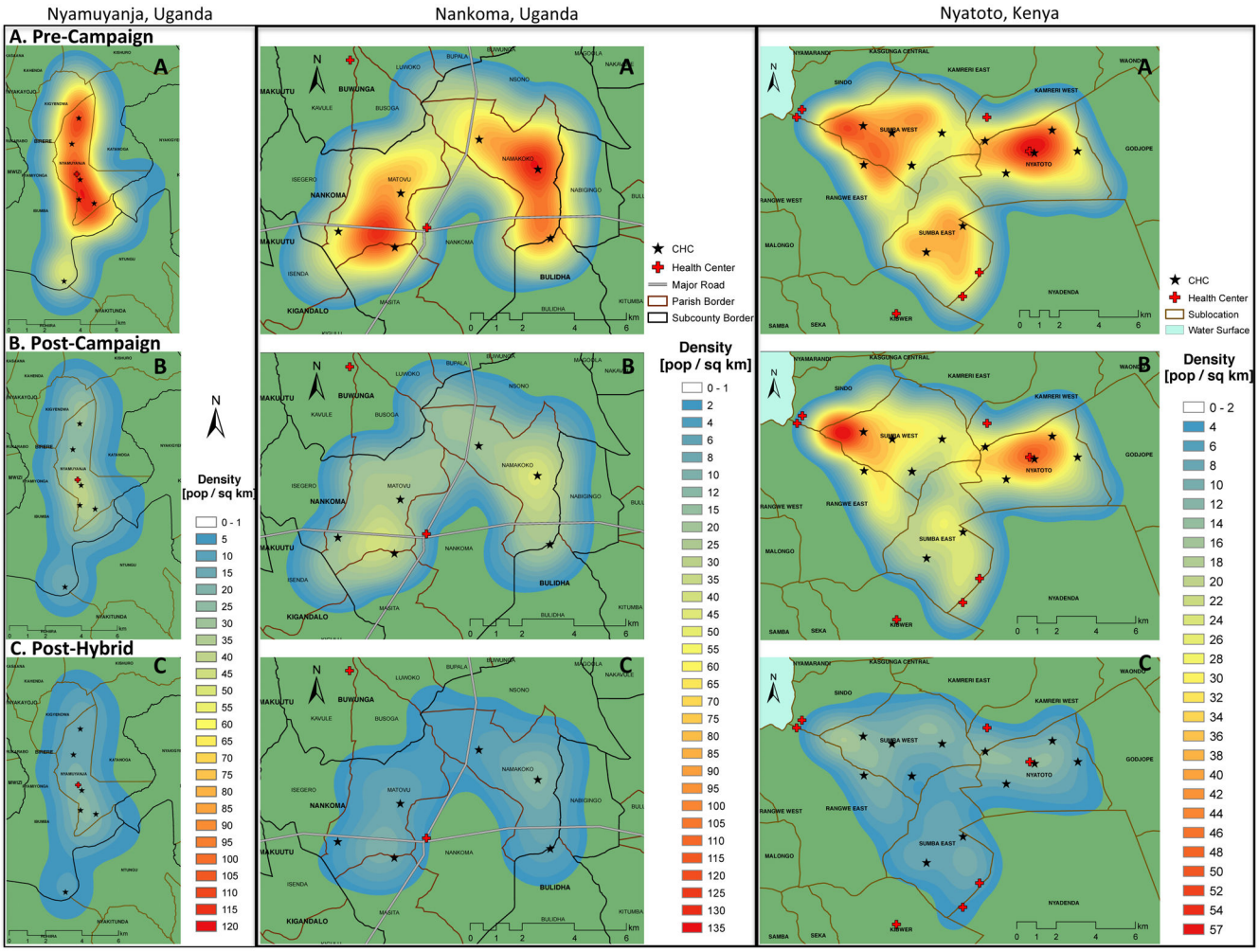


**Figure 2. Density of HIV Un-Tested Persons Over Time**

Three selected communities (one per region: Nyamuyanja in southwestern Uganda, Nankoma in eastern Uganda, and Nyatoto in western Kenya), with density of stable adult residents who have *not* participated in HIV testing from the year prior to study start through the end of the hybrid mobile testing approach, viewed at three time points: A) In the one year *before* implementing the hybrid mobile HIV testing approach, based on self-report; B) *Upon completing* community health campaign (CHC) implementation; C) *After* the hybrid mobile testing approach (combined CHC-based and home-based testing). Color intensity ranges from blue (HIV tested) to red (HIV untested), based on density of untested persons (population/square kilometer). Red crosses indicate location of government-run health facilities, and stars indicate locations of CHCs.

## Table 1

Baseline SEARCH Trial community adult (≥15 years) resident demographic characteristics, by study region.

| | Eastern Uganda | Southwestern Uganda | Western Kenya | Total |
|---|---|---|---|---|
| **Uganda (2002) & Kenya (2009) National Census Projections 2012** | 54,108 | 51,850 | 66,633 | 172,591 |
| **N (Population by Study Census)** | 51,561 | 54,654 | 62,557 | 168,772 |
| **Stable Residents** | 47,445 (92%) | 47,074 (86%) | 52,387 (84%) | 146,906 (87%) |
| **Median Age (IQR)** | 29 (20–44) | 29 (21–43) | 29 (20–43) | 29 (20–43) |
| **Female** | 27,639 (54%) | 28,699 (53%) | 33,203 (53%) | 89,541 (53%) |
| **Marital Status** | | | | |
| Single | 15,483 (30%) | 18,308 (34%) | 20,324 (32%) | 54,115 (32%) |
| Married | 30,156 (59%) | 30,015 (55%) | 35,480 (57%) | 95,651 (57%) |
| Widowed/Divorced/Separated | 5,714 (11%) | 6,226 (11%) | 6,558 (11%) | 18,528 (11%) |
| **Polygamy (% of married adults)** | 7,452 (25%) | 3,711 (12%) | 8,813 (25%) | 19,976 (21%) |
| **Occupation** | | | | |
| Farmer | 30,439 (59%) | 27,685 (51%) | 21,991 (35%) | 80,115 (48%) |
| Fisher | 116 (0.2%) | 147 (0.3%) | 6,211 (10%) | 6,474 (4%) |
| Student | 11,404 (22%) | 11,097 (20%) | 15,425 (25%) | 37,926 (22%) |
| No job | 1,794 (4%) | 2,451 (5%) | 4,950 (8%) | 9,195 (5%) |
| Other | 7,808 (15%) | 13,274 (24%) | 13,980 (22%) | 35,062 (21%) |
| **Education** | | | | |
| No Education | 7,581 (15%) | 9,217 (17%) | 3,680 (6%) | 20,478 (12%) |
| Primary School only | 30,112 (58%) | 29,323 (54%) | 40,534 (65%) | 99,969 (59%) |
| Any Secondary School | 13,766 (27%) | 16,077 (29%) | 18,099 (29%) | 47,942 (28%) |
| **Household: median number of acres owned (IQR)** | 1 (0.5–2) | 2 (1–3) | 1.5 (0.5–3) | 1.5 (0.5–3) |
| **Households with phone ownership** | 9,859/19,437 (51%) | 13,131/19,959 (66%) | 17,174/23,267 (74%) | 40,164/62,663 (64%) |
| **Households with electricity in home** | 719/19,437 (3.7%) | 936/19,959 (4.7%) | 596/23,267 (2.6%) | 2,251/62,663 (3.6%) |

**Table 2**

Stable adult resident population HIV testing coverage by mobile testing modality, and by country of residence, gender, and age. HIV prevalence, CD4 cell count, and self-reported new HIV diagnosis by mobile testing modality.

| | Enumerated Population (Stable Adults) | Community Health Campaign (CHC)-based Testing Coverage | Home-based Testing (HBT) Coverage | Hybrid Testing (CHC+HBT) Coverage |
|---|---|---|---|---|
| *Stable Adult Residents* | 146,906 | 104,635 (71%) | 26,672 (18%) | 131,307 (89%) |
| *Coverage by sub-group* | | | | |
| Uganda | 94,519 | 71,867 (76%) | 13,748 (15%) | 85,615 (91%) |
| Kenya | 52,387 | 32,768 (62%) | 12,924 (25%) | 45,692 (87%) |
| Men | 66,726 | 42,622 (64%) | 14,771 (22%) | 57,393 (86%) |
| Women | 80,180 | 62,013 (77%) | 11,901 (15%) | 73,914 (92%) |
| Age, in years | | | | |
| 15–19 | 28,738 | 19,753 (69%) | 5,952 (21%) | 25,705 (89%) |
| 20–49 | 88,415 | 62,435 (71%) | 16,211 (18%) | 78,646 (89%) |
| ≥50 | 29,753 | 22,447 (75%) | 4,509 (15%) | 26,956 (91%) |
| HIV prevalence, stable adults who tested | - | 9,781/104,635 (9.4%) | 3,004/26,672 (11.3%) | 12,785/131,307 (9.7%) |
| Median CD4 (IQR) cells/μL | - | 522 (359–714) | 503 (347–681) | 518 (356–707) |
| New HIV diagnosis* | - | 3,612/9,781 (37%) | 1,202/3,004 (40%) | 4,814/12,785 (38%) |

*New HIV diagnosis was defined at the time of testing for HIV at CHC or HBT, by self-report of either a) no prior HIV testing, or b) last prior HIV test was negative or unknown.

**Table 3**

Multivariable analysis evaluating predictors of: **A)** No prior HIV testing (by self-report) among stable adult residents who tested for HIV with the hybrid mobile approach. **B)** Requiring home-based HIV testing (HBT: i.e. not participating in testing at a community health campaign [CHC]) among stable adult residents who tested for HIV with the hybrid mobile testing approach; and **C)** Not testing for HIV among all stable adult residents (including persons who refused HIV testing at a CHC or during HBT), despite the hybrid mobile testing approach.

| | A) Relative Risk (95% CI) of no prior HIV testing | B) Relative Risk (95% CI) of requiring home-based HIV testing | C) Relative Risk (95% CI) of not testing for HIV |
|---|---|---|---|
| Uganda resident | Ref. | Ref. | Ref. |
| Kenya resident | 0.52 (0.51–0.53) | 1.82 (1.77–1.87) | 1.46 (1.41–1.50) |
| Female | Ref. | Ref. | Ref. |
| Male | 1.28 (1.26–1.29) | 1.48 (1.45–1.51) | 1.52 (1.48–1.56) |
| Non-single marital status | Ref. | Ref. | Ref. |
| Single | 1.33 (1.31–1.34) | 1.39 (1.36–1.42) | 1.70 (1.66–1.75) |
| Age, in years | | | |
| 15–19 | Ref. | Ref. | Ref. |
| 20–29 | 0.77 (0.76–0.78) | 1.26 (1.21–1.32) | 1.35 (1.27–1.43) |
| 30–39 | 0.71 (0.70–0.73) | 1.11 (1.05–1.17) | 1.58 (1.52–1.65) |
| 40–49 | 0.78 (0.77–0.79) | 1.00 (0.96–1.04) | 0.85 (0.77–0.94) |
| ≥50 | 1.02 (1.01–1.04) | 0.97 (0.94–1.00) | 1.18 (1.12–1.24) |
| Occupation | | | |
| Unemployed | Ref. | Ref. | Ref. |
| Farmer | 0.92 (0.89–0.95) | 0.61 (0.58–0.64) | 0.73 (0.67 –0.79) |
| Fisher | 0.81 (0.78–0.85) | 0.80 (0.75–0.85) | 0.98 (0.90–1.08) |
| Student | 1.21 (1.18–1.25) | 0.82 (0.79–0.85) | 0.73 (0.69–0.77) |
| Other employment | 0.87 (0.84–0.90) | 0.91 (0.86–0.96) | 1.10 (1.02–1.19) |
| Education | | | |
| No education | Ref. | Ref. | Ref. |
| Primary education only | 0.86 (0.84–0.88) | 0.85 (0.83–0.88) | 0.84 (0.80–0.89) |
| Any secondary education, or more | 0.67 (0.65–0.69) | 0.97 (0.94–1.00) | 1.08 (1.01–1.17) |

| | A) Relative Risk (95% CI) of no prior HIV testing | B) Relative Risk (95% CI) of requiring home-based HIV testing | C) Relative Risk (95% CI) of not testing for HIV |
|---|---|---|---|
| Wealth quintile | | | |
| 1 | Ref. | Ref. | Ref. |
| 2 | 0.90 (0.89–0.92) | 0.96 (0.92–1.00) | 0.94 (0.89–0.99) |
| 3 | 0.86 (0.84–0.88) | 0.96 (0.92–1.00) | 0.92 (0.87–0.97) |
| 4 | 0.85 (0.83–0.86) | 0.99 (0.95–1.03) | 0.89 (0.84–0.94) |
| 5 | 0.83 (0.82–0.85) | 1.13 (1.09–1.17) | 0.97 (0.91–1.03) |
| Months away from community in year prior to enrollment (up to 6 months) | | | |
| None | N/A | Ref. | Ref. |
| ≥1 Month | | 1.36 (1.31–1.40) | 1.60 (1.53–1.68) |
| HIV-uninfected | N/A | Ref. | N/A |
| HIV-infected | | 1.12 (1.08–1.16) | |